CHAPTER 12

NORTHERN ROCKFISH

by

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Executive Summary

This year marks the initial use of an age-structured model for BSAI northern rockfish. The change in assessment methodology was made possible by the reading of archived otoliths from AI trawl surveys, and the assessment methods were presented to the BSAI Plan Team at the September, 2003, meeting. The change in assessment methodology results in management recommendations based on Tier 3 criteria of Amendment 56 of the NPFMC BSAI Groundfish FMP. In contrast, previous assessments based northern rockfish management recommendations upon Tier 5 criteria. The change in assessment methodology requires the use of several data types that were previously not used, including catch data, length and age composition data from the fishery, age data from the AI trawl survey, size at age data and the estimation of growth curves, and maturity data.

Changes in the Assessment Results

(1) A summary of the 2003 assessment recommended ABC's relative to the 2002 recommendations is as follows:

	Assessment Year	
	2002 (Tier 5)	2003 (Tier 3)
ABC	6,998 t	6,881 t
OFL	9,019 t	8,136 t

SSC comments on rockfish harvest policy

The April, 2003, SSC minutes note that the SSC discussed "*whether a more conservative harvest rate (F50%) would be desirable for rockfish species in the GOA and BSAI*", and specifically requested that "*stock assessment analysts evaluate the harvest strategy for rockfishes during the TAC-setting process this fall.*"

An additional harvest policy evaluation that incorporated process error and measurement error as described in the Programmatic Supplemental Environmental Impact Statement (PSEIS) bookend 3b was included in the assessment. The methodology was to apply an uncertainty factor to $F_{35\%}$ in order to produce an alternative F_{abc}, which would be used if it was lower than F_{abc} produced under the status quo harvest policy. Because the northern rockfish age-structured model is new, an uncertainty factor for this stock was not computed for the PSEIS, and the uncertainty factor for GOA northern rockfish was applied. However, the uncertainty factor was sufficiently large that the alternative F_{abc} was not lower than F_{abc} produced from the status quo harvest policy. Additional harvest policy evaluations will be prepared for the December meeting of the SSC.

INTRODUCTION

Northern rockfish (*Sebastes polyspinus*) in the Bering Sea/Aleutians Islands (BSAI) region have been previously assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP, and have relied solely upon recent survey biomass estimates for an estimation of stock size. As such, the age composition of the stock, and size and proportion mature at age, were not considered in the previous assessments. The reading of archived otoliths from the AI surveys allowed the development of an age-structured model for northern rockfish. The methodology for this model follows closely that used for BSAI Pacific ocean perch, and was presented to the BSAI Plan Team at the September, 2003, meeting. This assessment marks the initial use of the age-structured model for management purposes. The major changes in this years assessment include introduction of new assessment methodology and because management advice as a separate species. For these reasons, the northern rockfish assessment is presented in a separate chapter from the remaining “other red rockfish”, which now consist of shortraker and rougheye rockfish.

Information on Stock Structure

A variety of types of research can be used to infer stock structure northern rockfish, including larval distribution patterns and other life-history information, and genetic studies. In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999, primarily in the Gulf of Alaska). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicates that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most are small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (POP), *S. polyspinus* (northern rockfish), and *S. ciliatus* (dusky rockfish).

An initial genetic revealed no evidence of population structure in Alaskan northern rockfish from either mtDNA or microsatellite analysis (Gharrett 2003), based upon small samples of 20 fish from each of three locations (Kodiak Island, Unimak Pass, and Stalemate Bank). Although the sample sizes were small and had little power, the authors concluded that the analysis was sufficient to conclude that existing structure is not pronounced. However, this study looked at only a portion of the mtDNA genome and a handful of microsatellite loci, and had small sample sizes. Also, the failure to identify population structure does not necessarily imply that northern rockfish consist of a single population unit. If subtle differences occur, much larger sample sizes would be required in order to identify stock structure.

FISHERY

BSAI foreign and joint venture rockfish catch records from 1977 to 1989 are available from foreign "blend" estimates of total catch by management group, and observed catches from the North Pacific Observer Program database. The foreign catch of BSAI rockfish during this time was largely taken by Japanese trawlers, whereas the joint-venture fisheries involved partnerships with the Republic of Korea. Because northern rockfish are taken as bycatch in the BSAI area, historical foreign catch records have not identified northern rockfish catch by species. Instead, northern rockfish catch has been included in a variety of management categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988). Foreign harvest was calculated by estimating the species composition of observed catches from the North Pacific Observer Program database, and applying those estimates to the "blend" estimates of total catch of the appropriate management category.

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. From 1991 to 2000, northern rockfish harvest in the EBS was included in the "other red rockfish" category, whereas harvest in the Aleutian Islands was reported in a "northern/sharpchin" category. In 2001, northern rockfish in the EBS were managed in a "northern/sharpchin" category, matching the species complex in the AI, and the management was combined across the BSAI area. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. Estimates of domestic catch since 1991 were made in a similar manner as the foreign catches. Estimates of domestic catch in 1990 were obtained from Guttormsen et al 1992. Northern rockfish catches from the domestic fishery prior to the start of the domestic observer program were obtained from PACFIN records.

Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977) (Table 12.1). Harvest data from 2000-2002 indicates that approximately 90% of the BSAI northern rockfish are harvested in the Atka mackerel fishery, with a large amount of the catch occurring in September in the western Aleutians (area 543). The distribution of northern rockfish harvest by Aleutian Islands subarea reflects both the spatial regulation of the Atka mackerel fishery and the increased biomass of northern rockfish in the western Aleutian Islands. Northern rockfish are patchily distributed and are harvested in relatively few areas within the broad management subareas of the Aleutian Islands, with important fishing grounds being Petral Bank, Sturdevant Rock, south of Amchitka I., and Seguam Pass (Dave Clausen, NMFS-AFSC, personal communication). The removals of northern rockfish from the trawl and hydoracoustic surveys are shown in Table 12.2.

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discard. This management category was used in 2001 in the EBS, and from 1993-2001 in the

AI. The discards rates are generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 12.3). The recent discard rates in the Aleutian Islands have been high, over 97% in both 2001 and 2002.

DATA

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 12.4). In some years, such as 1984 and 1987 over 700 fish lengths were obtained but these data samples came from a limited number of hauls. Additionally, the length data from the foreign fishery tended to originate from predominately one location in each year, and was not consistent between years. For example, the 1977 and 1978 fishery length data were collected from Tahoma Bank in the western Aleutians, whereas samples in 1984 were obtained from Seguam Pass and samples in 1987 were obtained from Petral Bank. In the domestic fishery, changes in observer sampling protocol since 1999 improved the distribution of hauls from which northern rockfish age and length data were collected.

In this assessment annual length frequency data were selected on the basis of consistency in sampling location and the number of samples collected. Foreign fishery length data from 1977 and 1978 were used, in part, because of the consistency in their sampling location, the increased numbers of hauls from which they were obtained, and the absence of other length composition data during this portion of the time series. Domestic fishery length data from 1996 and 1998-2001 are used, and the length and age data from 2002 are used to construct an estimated age-frequency of the fishery catch.

Survey data

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys, conducted by the National Marine Fisheries Service (NMFS) were conducted in 1988 and 1991 on the eastern Bering Sea slope, and in 1991, 1994, 1997, 2000, and 2002 in the Aleutian Islands (Table 12.5). Previous assessments have determined northern rockfish biomass by averaging recent survey results, thus placing considerable weight upon the biomass estimate from each year. The AI cooperative surveys during the 1980s were not used in previous assessments due to the more recent information from the NMFS trawl surveys, and also differences in vessels and gear design from the U.S. domestic surveys (Skip Zenger, National Marine Fisheries Service, pers. comm.). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys.

In this assessment, it is proposed that the AI surveys from the 1980s be used to provide some indication of biomass during this time period. The survey time series beginning in 1980 is considered as one data set, and no attempt is made to estimate a separate catchability coefficient for the cooperative surveys in the 1980s. In future assessments, the feasibility of reanalyzing the data from the cooperative surveys will be investigated, which would involve estimating fishing power corrections and re-estimating biomass levels and survey length with current (post 1990) survey strata. For the current assessment, the inclusion of the age and length composition data and catch data reduces the degree of influence of these biomass estimates (relative to an averaging of biomass estimates), as does the rather large standard deviations of estimated biomass; for example, the coefficient of variation (CV) ranges between 0.36 in 1983 to 1.3 in 1980 (Table 12.5).

As with the BSAI POP assessment (Spencer and Ianelli 2002), the Aleutian Islands U.S. trawl surveys are considered an index of the BSAI population. Northern rockfish are currently managed as a single stock in the BSAI area, and the available survey data indicates the bulk of the population is in the Aleutian Islands. Thus, the Aleutian Islands survey, which covers a portion of the EBS management area, is a useful index of the population. Although a new biennial EBS slope survey was initiated in 2002 (after some gear trials in 2000), the resulting biomass estimate was small (33 t) relative to the Aleutian Islands and had a relatively high coefficient of variation (38%). As the new biennial EBS slope survey proceeds in the future, the resulting data will be evaluated for suitability for incorporating into the northern rockfish model.

The biomass of northern rockfish is concentrated largely in the western Aleutian Islands, with an average of 72% of the estimated biomass from the 1991-2002 NMFS AI trawl surveys occurring in this region (Table 12.5). The coefficients of variation (CV) of these biomass estimates by region are generally high, but especially so in the southern Bering Sea portion of the surveyed area (165 W to 170 W), where the CV was less than 0.60 only in the 2000 survey.

Biological Data

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of otoliths collected and lengths measured are shown in Table 12.6, along with the number of hauls producing these data. The survey data produce reasonable sample sizes of lengths and otoliths from throughout the survey area. The maximum age observed in the survey samples was 72 years.

The survey otoliths were read with the break and burn method, and were thus considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from Courtney et al. 1991, based on two independent readings of otoliths from the Gulf of Alaska trawl survey from 1984-1993. The raw data in Courtney et al. (1999) was used to estimate the standard deviation for each age assigned by one reader, and it was assumed the age assigned by the other reader was accurate. The standard deviations were regressed against age to provide a predicted estimate of standard deviation of observed ages for a given true age, and this linear relationship was used to produce the aging error matrix is shown in Table 12.7.

The von Bertalanffy growth curves estimated from the survey data show differences between the three regions of the Aleutian Islands, with the length at infinity (L_{inf}) increasing from west to east (Figure 12.1):

AI subarea	$\mathbf{L_{inf}}$	**K**	$\mathbf{t_0}$
West (area 543)	32.95	0.14	-1.36
Central (area 542)	33.44	0.20	0.06

East (area (541)	37.91	0.17	-0.11
All areas	33.79	0.19	-0.016

The proposed model does not divide the BSAI population into subareas, and the von Bertalanffy growth curve obtained from samples collected in all areas is used in the model.

The scatterplot of length at age, and the fitted von Bertalanffy growth curve, are shown in Figure 12.2, and were useful in determining the number of age and length bins for the model. Few northern rockfish less than 15 cm or younger than age 3 were observed, so these were chosen as lower bounds of the length and age bins, respectively. Expected size of northern rockfish is very close to the length at infinity of 34 cm by about age 23, making inferences on age structure from the length composition difficult for fish older than 23 years. Thus, the terminal plus groups for the modeled size and age structure were 34+ cm and 23+ years, respectively. The von Bertalanffy growth curve was truncated at 23 years, as any adjustment for increased size of older individuals in the plus group would make little difference for northern rockfish.

A transition matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin (Table 12.8). This matrix was created by regressing the observed standard deviation in length at each age against age, and the predicted relationship was used to produce some variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.16 at age 3 to 0.12 at age 23.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1986-2000, and produced estimates of a = 1.25 x 10^{-5} and b = 3.05. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 12.9).

In recent years, the proportion of northern rockfish in large size bins has been less in the AI survey relative to samples obtained in the fishery (Figure 12.3), and it will be seen later that this pattern influences the estimated fishery selectivity curve.

The following table summarizes the data available for the BSAI northern rockfish model:

Component	BSAI
Fishery catch	1977-2003
Fishery age composition	2002
Fishery size composition	1977, 1978, 1996, 1998-2001
Survey age composition	1991, 1994, 1997, 2000, 2002
Survey biomass estimates	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002

ANALYTIC APPROACH

Model structure

The assessment model for northern rockfish is very similar to that currently used for BSAI Pacific ocean perch, which was used as a template for the current model. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 \le a < A, \quad 1977 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 23), and T is the terminal year of the analysis (defined as 2003). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The numbers at age in the first year are estimated as

$$N_a = R_0 e^{-M(a-3)+\gamma_a}$$

where R_0 the number of age 3 recruits for an unfished population and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_r, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 1996 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν_t is a time-variant deviation. The recruitments from 1997 to 2003 are set the median recruitment, e^{μ_r}.

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) that increases asymptotically with age and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishsel_a * f_t \equiv fishsel_a * e^{(\mu_f + \varepsilon_t)}$$

The logistic curve is used to model fishery selectivity at age:

$$fishsel_a = \frac{1}{1 + \exp(-slope(a - a_{50\%}))}$$

where the $a_{50\%}$ and *slope* parameters control the age at 50% maturity and the slope of the curve at this point, respectively.

Initial model runs indicated that that reasonable fishing selectivity parameters could not be estimated from the available data, as the age at 50% maturity was estimated as 19 years. This result stems from the greater proportion of fish in the larger size bins in the fishery length composition relative to the survey length composition (Figure 12.3). Reasonable estimates of survey selectivity, also modeled with a logistic curve, were obtained, and it is not expected that the fishery selectivity would differ substantially from the survey selectivity. The fishing selectivity parameters were estimated as the survey selectivity parameters multiplied by e^{γ}, where γ was normally distributed with a mean of zero and a standard deviation of 0.03 and 0.05, respectively, for the $a_{50\%}$ and *slope* parameters, respectively.

The mean numbers at age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred\_biom_t = qsurv \sum_a \left(\overline{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability.

To facilitate parameter estimation, prior distributions were used for the survey catchability *qsurv* and the natural mortality rate *M*. The prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.30 (obtained from the 2002 BSAI POP assessment model). A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.06 (the value used in previous assessments, based upon expected relationships between *M*, longevity, and the von Bertalanffy growth parameter *K* (Alverson and Carney 1975)) and the CV set to a 0.25. The standard deviation of log recruits, σ_r, was also modeled with a prior lognormal distribution, although the CV was set so low (0.001) so as to essentially fix this parameter at a constant level. This choice was motivated by the increased potential for model instability when variance parameters are estimated, and a variety of choices for σ_r were evaluated.

Parameters Estimated Independently

The parameters estimated independently include the age error matrix, the age-length transition matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector are described above. The proportions of females mature at age (Table 12.9) was obtained from the Gulf of Alaska northern rockfish model (Courtney et al. 1999), and are a logistic curve fit to data collected by Chris Lunsford of the Auke Bay Laboratory.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that maximize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2}\right)^2}{2\sigma^2} + n\ln(\sigma)$$

The adjustment of adding $\sigma_r^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment. The log-likelihood of the recruitment of cohorts represented in the first year of the model treated in a similar manner:

$$\lambda_1 \sum_{a-1} \frac{(\gamma_t)^2}{2\sigma^2} + (a-1)\ln(\sigma)$$

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,t,l}\sum_{s,t,l} p_{f,t,l}\ln(\hat{p}_{f,t,l}) - p_{f,t,l}\ln(p_{f,t,l})$$

where n is the number of hauls which produced the data, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 \;/\; 2cv_t^{\,2}$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function. The overall negative log-likelihood function (excluding the catch component) is

$$\begin{aligned}
&\lambda_1\left(\sum_t\left(\frac{\nu_t+\sigma^2/2}{2\sigma^2}\right)^2 + n\ln(\sigma)\right) + \\
&\lambda_1\left(\sum_{a-1}\left(\frac{\gamma_t}{2\sigma^2}\right)^2 + (a-1)\ln(\sigma)\right) + \\
&\lambda_2\sum_t(\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv_t^2 + \\
&n_{f,t,l}\sum_{s,t,l} p_{f,t,l}\ln(\hat{p}_{f,t,l}) - p_{f,t,l}\ln(p_{f,t,l}) + \\
&n_{f,t,a}\sum_{s,t,l} p_{f,t,a}\ln(\hat{p}_{f,t,a}) - p_{f,t,a}\ln(p_{f,t,a}) + \\
&n_{surv,t,a}\sum_{s,t,a} p_{surv,t,a}\ln(\hat{p}_{surv,t,a}) - p_{surv,t,a}\ln(p_{surv,t,a}) + \\
&n_{surv,t,l}\sum_{s,t,a} p_{surv,t,l}\ln(\hat{p}_{surv,t,l}) - p_{surv,t,l}\ln(p_{surv,t,l}) + \\
&\lambda_3\sum_t(\ln(obs_cat_t) - \ln(pred_cat_t))^2
\end{aligned}$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data. The sample sizes for the age and length compositions were set to the number of hauls from which these demographic data were obtained. Additionally, because of the difficulty in fitting a fishery selectivity curve to the fishery age and length data, these data components were assigned one-half the weight assigned to the survey age compositions. The negative log-likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_t)	27
3) recruitment mean (μ_r)	1
4) recruitment standard deviation (σ_r)	1
5) recruitment deviations (ν_t)	20
6) historic recruitment (R_0)	1
7) first year recruitment deviations	20
8) biomass survey catchability	1
9) natural mortality rate	1
10) survey selectivity parameters	2
11) fishery selectivity parameters	2
Total parameters	77

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

RESULTS

Model evaluation

In order to evaluate the effect of σ_r, a series of models that varied the level at which this parameter was fixed were fit to the data (Table 12.10). The fit to the age composition and length composition data improved slightly as σ_r increased. The recruitment likelihood component had a higher negative log-likelihood as σ_r increased, and most of the changes in the overall model fit can be attributed to this component. A run eliminating the recruitment component of the likelihood function gave a better fit to the fishery length compositions and produced a root mean squared error of the recruitment residuals of 0.89. However, the lack of any constraints on recruitment in this model resulted in the estimated population in the first year of the model to consist predominately of age 10 fish. Additionally, the estimated Hessian matrix was not positive definite, indicating instability in the model fit.

The fit to the age and size composition data can be inferred from the comparison of the average input sample sizes (set to the number of hauls), by data type, to the effective sample size (Table 12.10). The effective sample size can be interpreted as the sample size that would be consistent with the fit produced by the model, and data components where the effective sample size exceeds the input sample size can be interpreted as good fits. The effective sample size for the survey age composition ranged from ~60% to ~72% of the input sample size. The effective sample sizes for the fishery age and size compositions indicate a poor fit to the data, as these data components were down-weighted relative to the survey age compositions.

The model run where σ_r was set to 0.75 and fishery selectivity was not estimated was defined as the base case, and the results below refer to this model run. This model had enough flexibility in estimated recruitment to match the year-class strengths inferred from the survey age and size data, and the level of σ_r is close to the root mean squared error of recruitment obtained when recruitment variability is not part of the likelihood function (0.89).

Biomass trends

The estimated survey biomass shows a relatively flat trend, starting at 131,684 t in 1977, increasing to 161,984 t in 1992, with a 2003 estimate of 137,564 t (Figure 12.4). The survey catchability was estimated at 1.12. The total biomass and spawning biomass showed similar patterns as the survey biomass, with the 2003 estimates being 143,604 t and 46,390 t, respectively (Figure 12.5). The time series of estimated total biomass, spawner biomass, and recruitment are shown in Table 12.11.

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 12.6-12.7, and the model fit to the survey age compositions are shown in Figure 12.8. The model captures the general trends in the survey age data, but does not completely match the magnitude of some of the peaks of these data. The estimated age at 50% selection for the survey and fishery selectivity curves were 6.66 and 7.21years, respectively (Figure 12.9). Recall that the fishery selectivity parameters are constrained by the survey selectivity parameters, and the fishery selectivity curve would tend to a higher age at 50% selectivity if this restraint was not in place.

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 12.10. A relatively high rate in 1977 is required to account for the relatively high catch in this year, followed by very low levels of fishing mortality during the 1980s when catch was small. Fishing mortality rates began to increase during the early 1990s, and the 2002 estimate is 0.030.

Recruitment

Recruitment strengths by year class are shown in Figure 12.11. There is little information to discern strong recruitments in the early years of the model, although strong year classes are observed in 1984, 1988, 1989, and 1993. These year class strengths can be seen in the survey age composition data, where the 1984 year class is revealed in the 1991 and 1994 age composition data, the1989 year class is revealed in the 1997 and 2000 age composition data, and the 1993 year class is revealed in the 2000 and 2002 age composition data. The scatterplot of recruitment against spawning stock biomass is shown in Figure 12.12, indicating little variation in estimated spawning stock biomass but more substantial variation in estimated recruitment for the modeled years.

Projections and Harvest Alternatives

The reference fishing mortality rate for BSAI northern rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2000 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 26,891 t. The year 2004 spawning stock biomass is estimated as 43,730 t. Since reliable estimates of the 2004 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B > B_{0.40}$ (43,730 > 26,891 t), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, the maximum permissible F_{ABC} is $F_{0.40}$, and F_{OFL} is constrained to be equal to $F_{0.35}$; the values of $F_{0.40}$ and $F_{0.35}$ are 0.059 and 0.070, respectively. The ABC associated with the $F_{0.40}$ level of 0.059 is 6,881 t. This ABC is approximately 117 t lower than last year's recommendation of 6,998 t. The estimated catch level for year 2004 associated with the overfishing level of F = 0.070 is 8,136 t. A summary of these values is below.

2004 SSB estimate (B)	=	43,730 t
$B_{0.40}$	=	26,892 t
$F_{0.40}$	=	0.059
F_{ABC}	=	0.059
$F_{0.35}$	=	0.070
F_{OFL}	=	0.070

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In previous assessments, this scenario has allowed the *max* F_{ABC} to be adjusted downward by a constant fraction corresponding to a value recommended in the stock assessment. For this assessment, this scenario computes a harvest rate corresponding to a downward adjustment of the $F_{35\%}$ based upon uncertainty correction factors used in Alternative 3.2 of the PSEIS. The F_{ABC} was then the minimum of the downward adjusted $F_{35\%}$ and the max F_{ABC}.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1998-2002 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

For scenario 2, the uncertainty correction factor used was that derived for GOA northern rockfish, which was 0.885. This uncertainty factor did not lower the $F_{35\%}$ below the *max* F_{ABC}, thus scenario 2 is equivalent to scenario 1.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the northern rockfish stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2004, then the stock is not overfished.)

Scenario 7: In 2004 and 2005, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2006 under this scenario, then the stock is not approaching an overfished condition.)

The projections of the mean spawning stock biomass, fishing mortality rate, and harvest for these scenarios are shown in Table 12.12. The results of these scenarios 6 and 7 indicate that the BSAI northern rockfish stock is neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2004 of scenario 6 is 1.85 times its $B_{35\%}$ value of 23,530 t. With regard to whether northern rockfish stock is likely to be overfished in the future, the expected stock size in 2006 of scenario 7 is 1.71 times the $B_{35\%}$ value.

OTHER CONSIDERATIONS

In previous assessments, the ABCs for northern rockfish were partitioned between the EBS and AI management areas as a precautionary measure. Because the AI trawl survey spans the two management areas, one option is to use the proportional survey biomass from the two areas to partition the ABCs as is done for BSAI Pacific cod. The average biomass from 1991-2002 in the AI management area is 155,108 t, whereas the average from the southern Bering Sea is 396 t; thus 99.7% of the estimated Aleutians Islands survey biomass for northern rockfish occurs in the Aleutian Islands management area. Because the Aleutian Islands survey does not cover the EBS slope, it may be useful to consider the 2002 EBS slope survey biomass of 33 t. The combined biomass in the EBS management area (33 t +396 t = 429 t) is 0.27 % of the combined BSAI biomass from both surveys of 155,537 t. Thus, it is recommended that 0.27% of the northern rockfish ABC, or 19 t, be allocated to the EBS region and 6,862 t be allocated to the AI region. These results are summarized below:

	AI ABC	EBS ABC	OFL
Northern rockfish	6,862 t	19 t	8,136 t

In 2002, the assessment authors recommended ABC and OFL levels based upon tier 5 criteria, with a single BSAI OFL and ABC partitioned between the EBS and AI management areas. Results from this method are summarized below; EBS biomass estimates were based upon the 2002 slope survey and the portions of the 1991-2002 AI trawl surveys within the EBS management area:

	AI ABC	EBS ABC	OFL
Northern rockfish	6,980 t	19 t	9,332 t

Thus, the ABC levels are close to that obtained with the Tier 5 methodology in 2002, and the OFL levels are more conservative. It should be noted that the SSC did not accept the EBS biomass estimates in 2002 and thus used Tier 6 methodology to determine the harvest recommendation for the EBS area. The Tier 3 assessment presented here does not use the EBS slope survey biomass estimates, thus providing a more conservative approach to the extent that unaccounted biomass along the EBS is not considered in determination of stock size and harvest levels.

ECOSYSTEM CONSIDERATIONS

Northern rockfish are plankton feeders, eating largely euphausids but also copepods, hermit crabs, and shrimp (Yang 1993). Small northern rockfish feed primarily on calanoid copepods, with the proportions of euphausids and myctophids increasing with northern rockfish size (Yang 2003).

BSAI northern rockfish are not currently targeted in the fishery, and approximately 90% of the harvest in recent years has come in the Atka mackerel fishery. Information on the ecosystem effects of the Atka mackerel fishery can be found in the Atka mackerel assessment in this SAFE document.

CONCLUSIONS

Notwithstanding the difficulty in estimating the fishery selectivity curve, the proposed model is viewed as an improvement over the previous Tier 5 assessments for northern rockfish, as information is obtained on year class strength and uncertainty in modeled parameters. The fishery data is crucial to the model, and the nature of the fishery, in terms of changes in fishing locations, gear, and seasonality, will be investigated in more detail in the future. As BSAI northern rockfish are a bycatch fishery, it is likely that there may be inter-annual variation in the fishing selectivity curve, as the spatial locations of the target fisheries which obtain northern rockfish may vary from year to year. Future models will investigate the feasibility of allowing fishing selectivity curves that vary over time.

Improvements of the model will depend largely on improving the input data. A maturity curve derived from BSAI northern rockfish will be useful, as the current maturity curve for the BSAI model was developed from GOA samples. Given the growth differences between BSAI and GOA northern rockfish, it is reasonable to expect differences in maturity as well. The earlier cooperative surveys in the 1980s could be reanalyzed in order to provide more meaningful biomass estimates that account for vessel differences within and between survey years, and the addition of the EBS slope survey will provide useful results as this time series develops.

SUMMARY

The management parameters for northern rockfish as presented in this assessment are summarized as follows:

Quantity	Value
M	0.067
Tier	3a
Year 2004 Total Biomass	141,809 t
Year 2004 Spawning stock biomass	43,730 t

$B_{100\%}$	67,229 t
$B_{40\%}$	26,892 t
$B_{35\%}$	23,530 t
F_{OFL}	0.070
Maximum F_{ABC}	0.059
Recommended F_{ABC}	0.059
OFL	8,136 t
Maximum allowable ABC	6,881 t
Recommended ABC	6,881 t

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Table 12.1. Catch of northern rockfish in the BSAI area.

	Eastern Bering Sea			Aleutian Islands			
Year	Foreign	Joint Venture	Domestic	Foreign	Joint Venture	Domestic	Total
1977	4			3,232			3,236
1978	21			549			570
1979	61			195			256
1980	49	9		221			279
1981	20	0		92			112
1982	63	8		177	0		248
1983	10	32		47	0		89
1984	26	6		11	185		229
1985	5	1		0	189		195
1986	5	41	15	0	193	15	270
1987	1	45	31		248	60	385
1988		4	36		438	55	534
1989		12	66		0	306	384
1990			247			1,235	1,481
1991			613			233	847
1992			328			1,541	1,868
1993			959			4,480	5,440
1994			47			4,666	4,712
1995			286			3,858	4,144
1996			116			6,637	6,753
1997			118			1,997	2,114
1998			47			3,674	3,721
1999			144			5,254	5,399
2000			114			4,737	4,851
2001			153			5,978	6,131
2002			112			3,601	3,713
2003			61			3969	4,030

Table 12.2. Estimated catch (t) of northern rockfish in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

		Area	
Year	AI	BS	BS-Hydroacoustic
1978		0.00	
1979		0.01	
1980	3.55	0.03	
1981		0.06	
1982	0.83	0.07	
1983	29.23	0.06	
1984		0.09	
1985		0.02	
1986	56.86	0.03	
1987		0.17	
1988		0.13	
1989		0.06	
1990		0.74	
1991	15.46	0.01	
1992		0.08	
1993		0.00	
1994	13.15	0.01	
1995			0.01
1996		0.00	
1997	17.67	0.03	0.03
1998		0.25	
1999		0.09	
2000	39.49	0.11	0.29
2001		0.04	
2002	36.34	0.02	0.32
2003		0.12	

Table 12.3. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NR), and northern rockfish catch in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The catches of the SC/NO group consist nearly entirely of northern rockfish. Prior to 2001, northern rockfish were managed as part of the ORR complex in the eastern Bering. Beginning in 2002, sharpchin rockfish were removed from other red rockfish and northern rockfish were managed with single-species catch levels. Unless otherwise noted, catch data were obtained from summaries produced by the NMFS Alaska regional office.

Area	Species Group	Year	Catch Retained	Discard	Total	Percentage
EBS	SC/NO	2001	15	138	153	90.2%
EBS	Northerns	2002	8	104	112	92.9%
AI	SC/NO	1993	320	4,166	4,486	92.9%
		1994	798	3,870	4,668	82.9%
		1995	1,207	2,665	3,872	68.8%
		1996	2,269	4,384	6,653	65.9%
		1997	145	1,852	1,997	92.7%
		1998	459	3,289	3,748	87.8%
		1999	521	4,735	5,256	90.0%
		2000	273	4,464	4,737	94.2%
		2001	171	5,807	5,978	97.1%
AI	Northerns	2002	96	3505	3601	97.4%

Table 12.4. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1974-2002.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls
1974					
1975					
1976					
1977	1202	16	230	224**	11
1978	759	11	148	148**	13
1979					
1980					
1981					
1982	334**	5			
1982					
1984	703**	4			
1985	12**	7	12	0	7
1986	100**	2	100	0	2
1987	976**	9	79	0	3
1988					
1989	80**	1	80	0	1
1990	403**	10			
1991	145**	7			
1992					
1993	1809**	13			
1994	767**	8			
1995	833**	9			
1996	4554	68			
1997	1**	1			
1998	543	13	30	29**	5
1999	917	42	50	0	24
2000	976	66	166	0	48
2001	661	67	136	0	59
2002	889*	67	200	195*	60

*Used to create age composition
**Not used

Table 12.5. Northern rockfish biomass estimates (mt) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

YEAR	Aleutian Islands Management Sub-Areas western	central	eastern	EBS estimates southern BS	Total
1980					43,653 (1.33)
1983					44,974 (0.34)
1986					181,056 (0.40)
1991	146,403 (0.21)	64,202 (0.18)	4,068 (0.52)	582 (0.63)	215,255 (0.16)
1994	70,669 (0.61)	15,832 (0.58)	5,933 (0.54)	855 (0.60)	93,289 (0.47)
1997	65,492 (0.38)	18,363 (0.55)	3,331 (0.58)	204 (0.68)	87,390 (0.31)
2000	142,393 (0.39)	37,949 (0.44)	24,957 (0.70)	49 (0.40)	205,348 (0.29)
2002	134,519 (0.33)	38,189 (0.43)	3,242 (0.42)	290 (0.67)	176,240 (0.27)
Average (1991-2002)	111,895	34,907	8,306	396	155,505
Percentage	72.0%	22.4%	5.3%	0.3%	

Table 12.6. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2002, with the number of hauls from which these data were collected.

Year	**Lengths**	**Hauls**	**Otoliths read**	**Hauls**
1991	4853	47	456	14
1994	6252	118	409	20
1997	7554	153	652	69
2000	7779	135	725	92
2002	9273	141	0	82

Table 12.7. Aging error matrix for BSAI northern rockfish, based upon data from Courtney et al 1999.

True age	Observed age 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	0.89	0.50	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.10	0.38	0.38	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.11	0.38	0.37	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.01	0.11	0.37	0.37	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.01	0.12	0.37	0.36	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.01	0.12	0.36	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.12	0.35	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.35	0.34	0.14	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.34	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.32	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.32	0.32	0.15	0.04	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.14	0.32	0.31	0.15	0.04	0.01	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.30	0.15	0.04	0.01
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.30	0.16	0.05
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.29	0.16
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.29	0.29
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.21	0.50

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Table 12.8. Transition matrix for BSAI northern rockfish, showing the proportion of a given age group expected in each length group.

Length (cm)	Age 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
15	0.66	0.19	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.13	0.12	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.09	0.15	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.06	0.16	0.10	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.03	0.14	0.13	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.01	0.11	0.15	0.09	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.07	0.15	0.12	0.06	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.04	0.13	0.14	0.09	0.05	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.02	0.10	0.15	0.12	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.01	0.06	0.13	0.14	0.11	0.07	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
25	0.00	0.00	0.04	0.10	0.14	0.13	0.10	0.07	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
26	0.00	0.00	0.02	0.07	0.13	0.14	0.12	0.10	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
27	0.00	0.00	0.01	0.04	0.10	0.13	0.13	0.12	0.10	0.08	0.07	0.06	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
28	0.00	0.00	0.00	0.02	0.07	0.11	0.13	0.13	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05
29	0.00	0.00	0.00	0.01	0.04	0.08	0.12	0.13	0.13	0.12	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.06
30	0.00	0.00	0.00	0.00	0.02	0.06	0.09	0.12	0.13	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08
31	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.09	0.11	0.12	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09
32	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.09	0.10	0.11	0.11	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10
33	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10
34	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.09	0.13	0.18	0.23	0.27	0.31	0.34	0.37	0.39	0.41	0.42	0.43	0.44

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Table 12.9. Predicted weight and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	47	0.021
4	87	0.030
5	133	0.044
6	182	0.065
7	230	0.093
8	275	0.132
9	317	0.185
10	354	0.252
11	387	0.333
12	415	0.426
13	440	0.524
14	461	0.621
15	479	0.708
16	494	0.783
17	506	0.843
18	517	0.888
19	526	0.922
20	533	0.946
21	539	0.963
22	544	0.975
23	548	0.983

Table 12.10. Comparison of negative log likelihood of model components, average effective and input sample sizes, and root mean squared errors for the survey and recruitment residuals.

	standard deviation of log recruits				
Component	0.25	0.5	0.75	1	no recruitment likelihood
Recruitment	-51.34	-22.05	-5.62	6.64	0.00
AI survey biomass	11.75	11.90	11.78	11.62	11.03
Catch	0.00	0.00	0.00	0.00	0.00
F penalty	5.24	5.23	5.18	5.13	4.94
Fishery ages	166.66	165.82	165.61	165.57	165.61
Fishery lengths	560.56	559.61	558.30	556.67	551.82
Survey ages	783.27	778.96	777.53	777.01	776.76
Prior for *q_srv*	0.05	0.10	0.13	0.15	0.26
Prior for *M*	0.23	0.20	0.17	0.15	0.07
Prior for σr	0.00	0.00	0.00	0.00	0.00
Prior for fish sel slope	0.01	0.01	0.01	0.01	0.01
Prior for fish sel 50%	3.41	3.44	3.56	3.69	3.99
Total likelihood	**1689.69**	**1711.34**	**1724.43**	**1734.59**	**1723.51**
AverageEffective Sample Size					
Fishery ages	25.64	26.49	26.63	26.61	26.45
Fishery lengths	9.04	9.78	10.95	13.08	46.60
Survey ages	35.62	38.16	39.16	39.68	40.50
Average Sample Sizes					
Fishery ages	60.00	60.00	60.00	60.00	60.00
Fishery lengths	41.29	41.29	41.29	41.29	41.29
Survey ages	55.40	55.40	55.40	55.40	55.40
Root Mean Squared Error					
survey	0.69	0.68	0.67	0.66	0.62
recruitment	0.16	0.36	0.53	0.73	0.89

Table 12.11. Estimated total biomass (t), spawner biomass (t), and recruitment (thousands) of BSAI northern rockfish.

Year	Total Biomass (ages 3+)	Spawner Biomass (ages 3+)	Recruitment (age 3)
1977	137,350	40,965	44,538
1978	137,280	41,161	33,136
1979	139,915	42,297	33,818
1980	143,282	43,551	43,988
1981	146,258	44,774	30,760
1982	149,099	46,014	28,736
1983	151,263	47,144	23,936
1984	152,901	48,266	20,408
1985	153,691	49,274	18,722
1986	154,296	50,238	27,705
1987	157,464	51,142	89,381
1988	159,996	51,943	36,725
1989	162,061	52,617	24,451
1990	164,076	53,272	26,353
1991	166,318	53,441	63,803
1992	169,353	53,816	48,985
1993	170,449	53,818	20,964
1994	167,064	52,557	15,370
1995	163,694	51,663	16,740
1996	162,009	51,093	57,444
1997	157,227	49,671	
1998	157,162	49,959	
1999	155,443	49,659	
2000	152,010	48,672	
2001	149,163	47,799	
2002	145,123	46,390	
2003	143,604	45,829	

Table 12.12. Projections of BSAI northern rockfish spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 26,891 t and 23,530 t, respectively.

Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	44695	44695	44695	44695	44695	44695	44696
2004	43730	43730	44047	43959	44367	43611	43733
2005	42013	42013	43547	43117	45138	41449	42018
2006	40412	40412	43086	42328	45940	39448	40312
2007	38925	38925	42663	41593	46768	37604	38420
2008	37529	37529	42250	40886	47584	35893	36661
2009	36254	36254	41881	40239	48417	34341	35064
2010	35100	35100	41556	39655	49263	32946	33625
2011	34067	34067	41278	39135	50117	31705	32341
2012	33134	33134	41025	38659	50947	30596	31190
2013	32309	32309	40808	38238	51763	29620	30172
2014	31595	31595	40643	37885	52583	28780	29289
2015	30983	30983	40523	37593	53401	28061	28527
2016	30457	30457	40438	37351	54207	27453	27874
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	0.033485	0.033485	0.033487	0.033487	0.033487	0.033485	0.033487
2004	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.058653
2005	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.058653
2006	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2007	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2008	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2009	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2010	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2011	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2012	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2013	0.058653	0.058653	0.029326	0.037438	0	0.069713	0.069713
2014	0.058653	0.058653	0.029326	0.037438	0	0.069712	0.069713
2015	0.058653	0.058653	0.029326	0.037438	0	0.069557	0.069624
2016	0.058653	0.058653	0.029326	0.037438	0	0.069019	0.069238
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2003	4030	4030	4030	4030	4030	4030	4030
2004	6881	6881	3489	4437	0	8136	6882
2005	6632	6632	3455	4361	0	7761	6633
2006	6405	6405	3425	4292	0	7422	7577
2007	6200	6200	3398	4229	0	7119	7267
2008	6019	6019	3375	4174	0	6853	6995
2009	5864	5864	3358	4128	0	6626	6760
2010	5732	5732	3345	4091	0	6433	6556
2011	5619	5619	3336	4060	0	6267	6379
2012	5520	5520	3329	4033	0	6123	6223
2013	5433	5433	3323	4009	0	5998	6086
2014	5357	5357	3318	3988	0	5889	5968
2015	5291	5291	3315	3971	0	5784	5860
2016	5234	5234	3313	3956	0	5666	5745

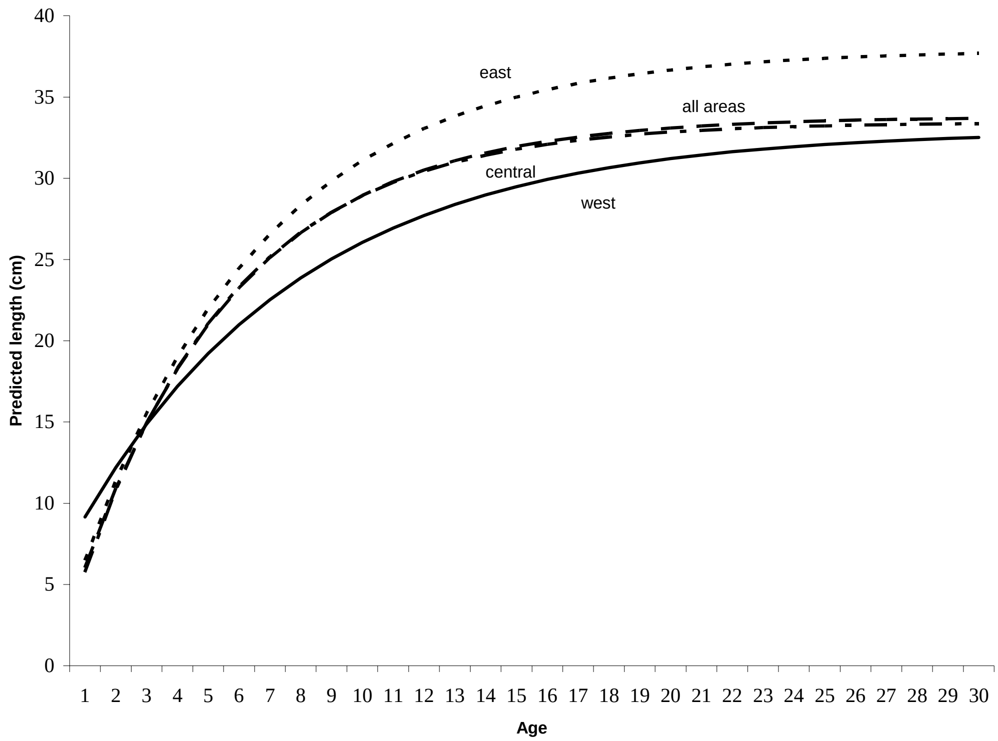

Figure 12.1. Estimated von Bertalannfy growth curves for Aleutian Islands northern rockfish, by subarea, from AI trawl survey samples collected from 1986-2002.

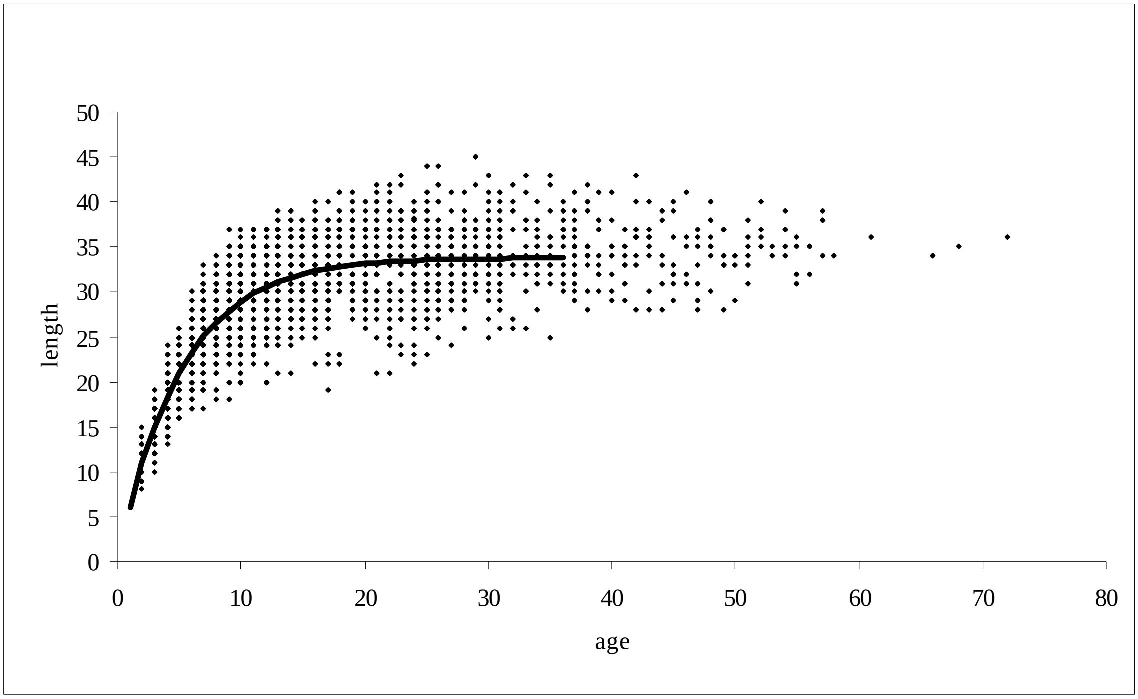

Figure 12.2. Scatterplot of northern rockfish length at age data, with estimated length at age.

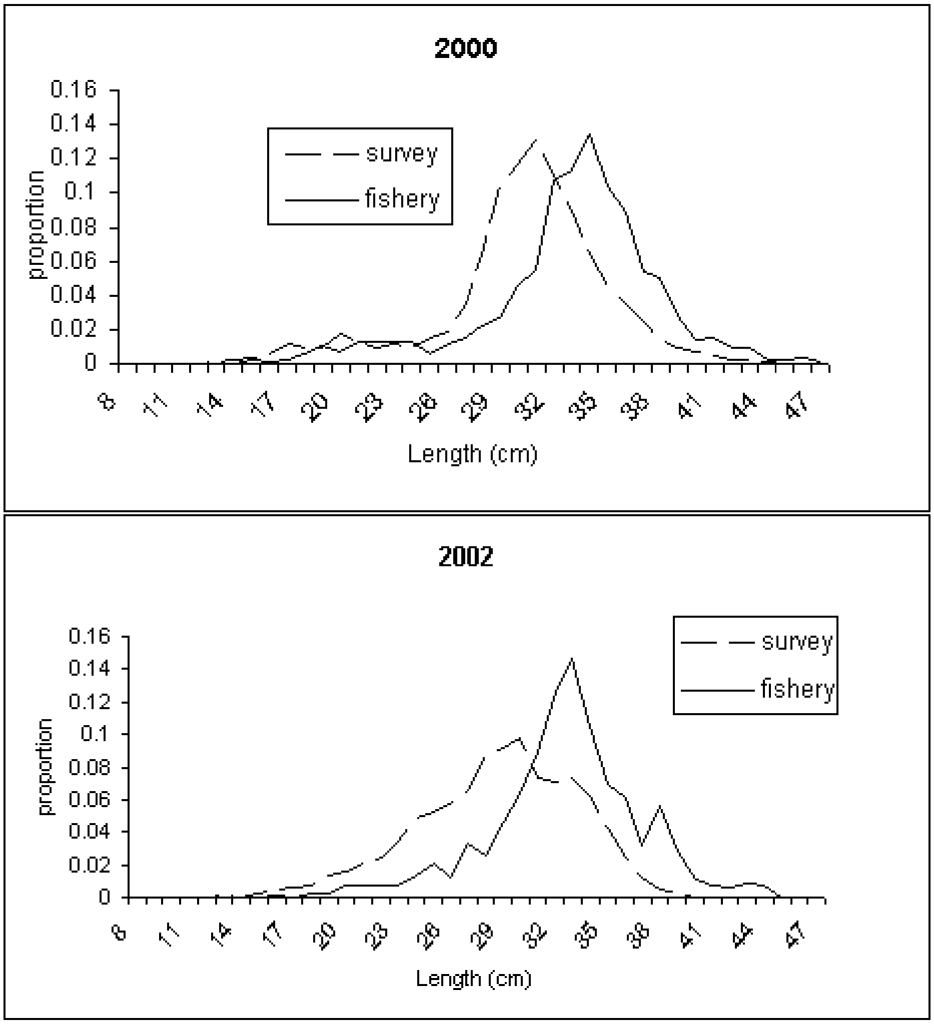

Figure 12.3. Length frequency distribution of northern rockfish from the 2000 and 2002 AI survey and fishery samples.

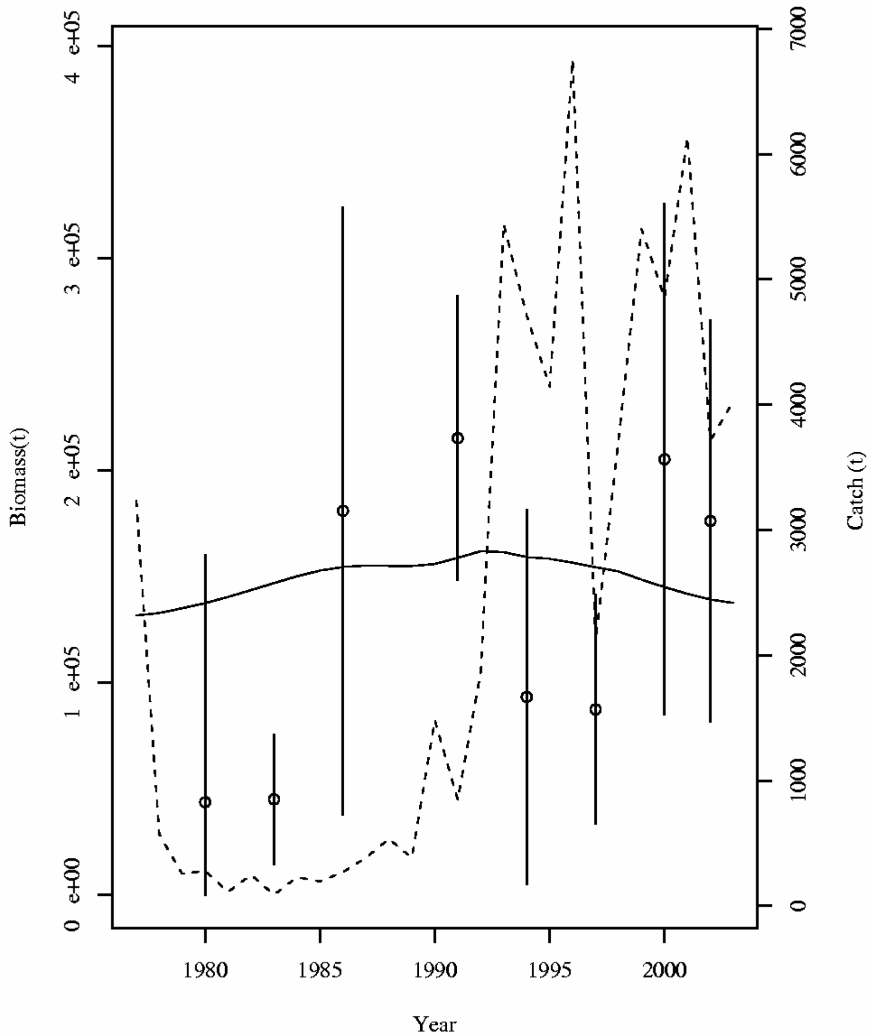

Figure 12.4. Observed AI survey biomass(data points, +/– 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

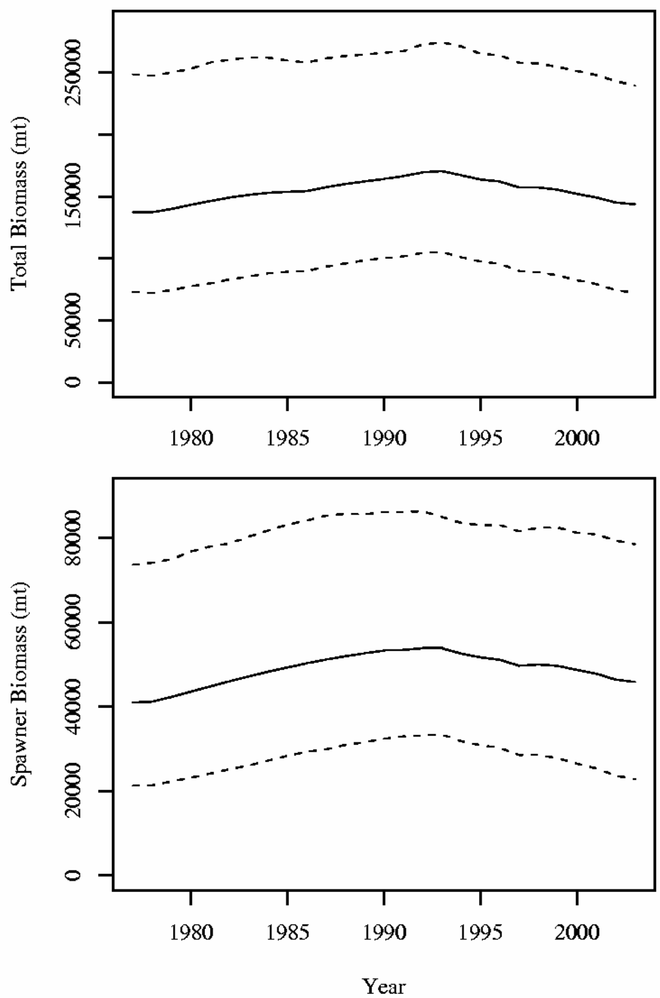

Figure 12.5. Total and spawner biomass for BSAI northern rockfish, with 95% confidence intervals from MCMC integration.

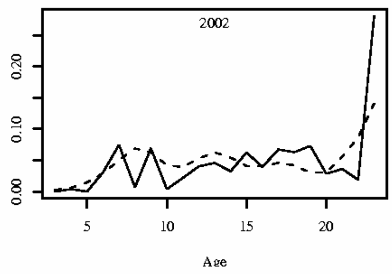

Figure 12.6. Fishery age composition by year (solid line = observed, dotted line = predicted)

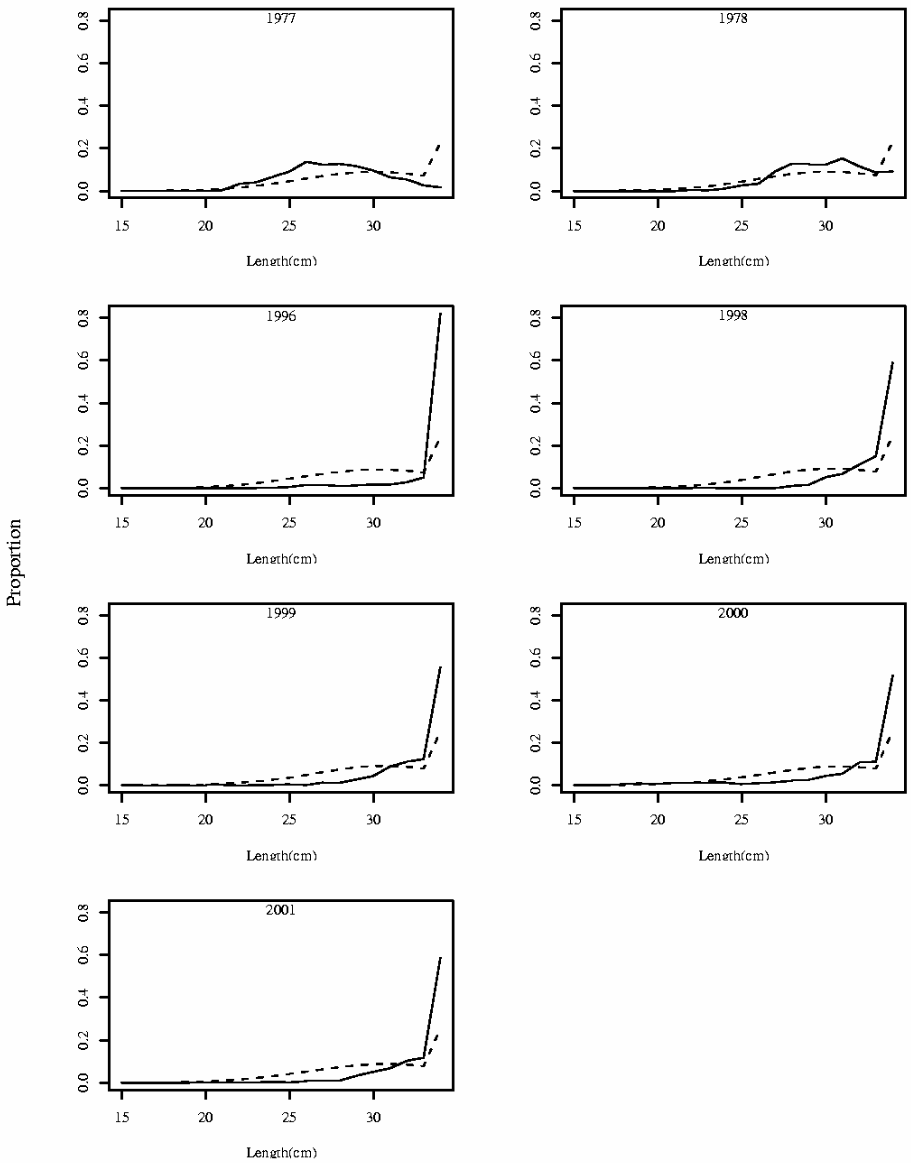

Figure 12.7. Fishery length composition by year (solid line = observed, dotted line = predicted)

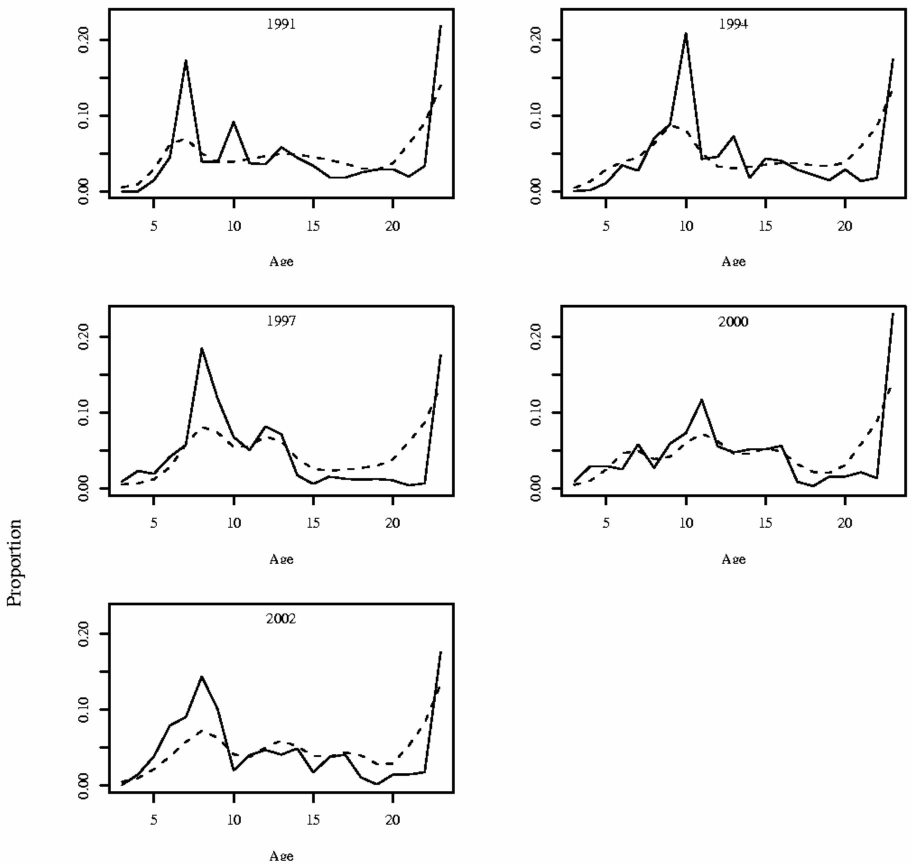

Figure 12.8. AI Survey age composition by year (solid line = observed, dotted line = predicted)

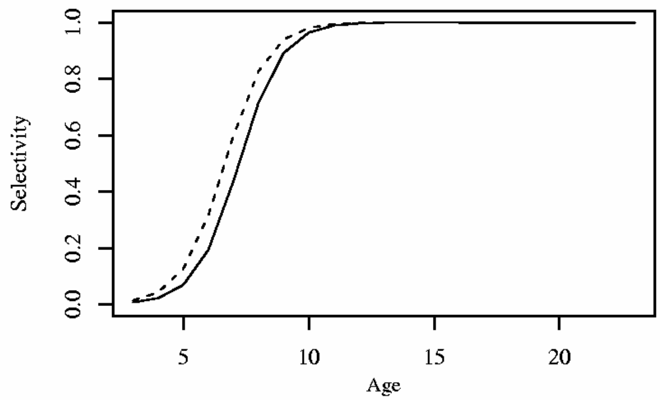

Figure 12.9. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

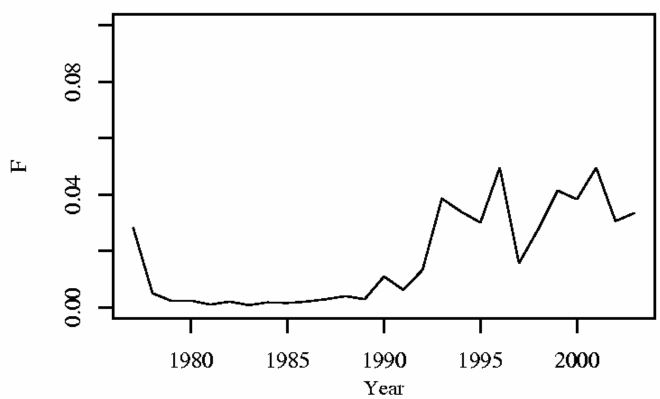

Figure 12.10. Estimated fully selected fishing mortality for BSAI northern rockfish.

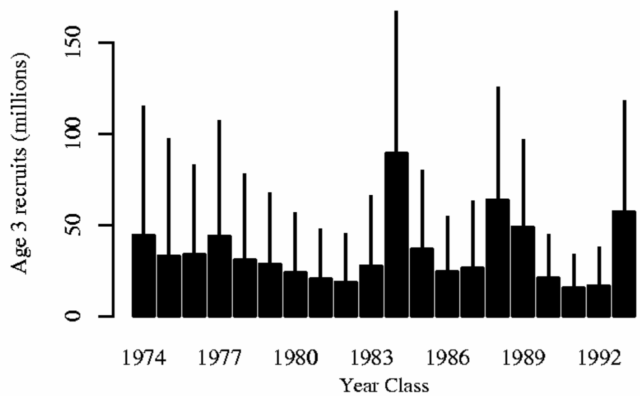

Figure 12.11. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

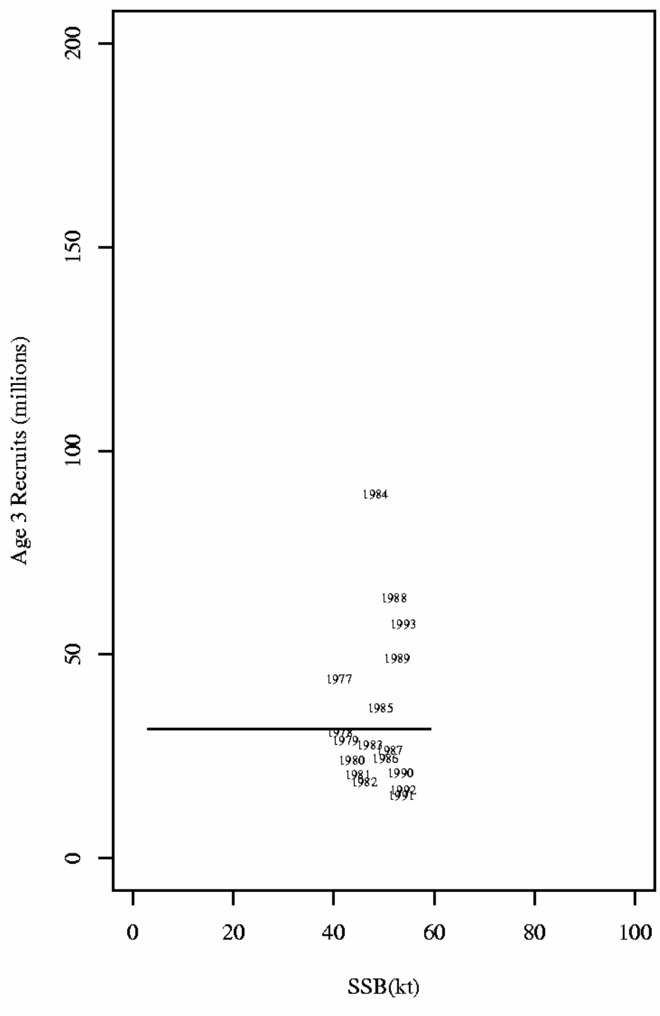

Figure 12.12. Scatterplot of BSAI northern rockfish spawner–recruit data; label is year class.